Optimization
Iranian Journal of Optimization
Volume 8, Issue 2, 2016, 87-100
Research Paper
Online version is available on: www.ijo.iaurasht.ac.ir
Islamic Azad University
Rasht Branch
E-ISSN:2008-5427

A Combined Group EA-PROMETHEE Method for a Supplier Selection Problem

Hamid Reza Rezaei-Kelidbari [1*], Mahdi Homayounfar [2] and Seyyed-e Fatemeh Alavi Foumani [3]

[1] Department of Public Administration, Rasht Branch, Islamic Azad University, Rasht, Iran
[2] Department of Industrial Management, Rasht Branch, Islamic Azad University, Rasht, Iran
[3] Department of Business Administration, Rasht Branch, Islamic Azad University, Rasht, Iran

Received: 28 June 2016
Accepted: 24 August 2016

Keywords:
Supply Chain Management (SCM)
supplier selection
fuzzy AHP
PROMETHEE

Abstract

One of the important decisions which impacts all firms' activities is the supplier selection problem. Since the 1950s, several works have addressed this problem by treating different aspects and instances. In this paper, a combined multiple criteria decision making (MCDM) technique (EA-PROMETHEE) has been applied to implement a proper decision making. To this aim, after reviewing the theoretical background regarding to supplier selection, the extension analysis (EA) is used to determine the importance of criteria and PROMETHEE for appraisal of suppliers based on the criteria. An empirical example illustrated the proposed approach.

***Correspondence E-mail**: hrezaee41@yahoo.com

INTRODUCTION

In today's fierce competitive environment, characterized by thin profit margins, high consumer expectations for quality products and short lead-times, companies are forced to take advantage of any opportunity to optimize their business processes. To reach this aim, academics and practitioners have come to the same conclusion: for a company to remain competitive, it has to work with its supply chain partners to improve the chain's total performance (Aissaoui et al., 2007). Supplier selection is one of the critical activities for firms to gain competitive advantage and achieve the objectives of the whole supply chain (Guneri et al., 2009).On average, manufacturers' purchases of goods and services constitute up to 70% of product cost and in high-technology firms, purchased materials and services represent up to 80% of total product cost (Ghodsypour & O'Brien, 2001). To manage this strategically important purchasing function effectively, appropriate method and criteria have to be chosen for the problem. Since, different and usually conflicting criteria have to be taken into account for evaluating and selecting the most promising alternative, the supplier (vendor) selection problem is a multi-criteria decision making and this problem needs to MCDM methods. In order to select the best supplier, this paper is organized as follows: first we present the brief literature about supplier selection researches and some mathematical methods in this sort of problems. The research methodology presented in Section 3. Section 4 proposed a two steps procedure, theoretically. A real world numerical example in an auto part manufacturer company is dealt with in section 5. Last section contains the conclusion.

LITERATURE REVIEW

The analysis of criteria for selection and measuring the performance of suppliers has been the focus of many scientists and purchasing practitioners since 1960's. An interesting work which is a reference for the majority of papers dealing with supplier selection problem was presented by Dickson (1966). His study was based on a questionnaire sent to 273 purchasing agents and managers selected from the membership list of the National Association of Purchasing Managers in US and Canada. Based on the total of 170 (62.3) responses received regarding the importance of 23 criteria for supplier selection; 'quality' of the product, the 'on time delivery', the 'performance history' of the supplier, the 'warranties and claim policies', 'production facilities and capacity' and 'price' determined as the most significant criteria in Dickson's study. Lehmann and O'Shaughnessy (1974) identified product types on the basis of the problems involved in their adoption by industrial buyers. The importance of 17 attributes to purchasing agents is then compared across these types of products in the United States and the United Kingdom. The results suggest some interesting strategies for industrial suppliers seeking increased adoption of their products.

Weber et al. (1991) present a classification of all the articles published since 1966 according to the treated criteria. Based on 74 papers, the observed that 'price', 'delivery', 'quality' and 'production capacity and location' are the criteria most often treated in the literature. Swift (1995) considered 21 supplier selection criteria of purchasing managers who have a preference for single sourcing and those who have a preference for multiple sourcing. The purpose of his study was to determine if there are substantial differences in supplier selection criteria between purchasing managers having dissimilar preferences for product sourcing decisions. Mummalaneni et al. (1996) proposed six attributes of on-time delivery, quality, price/cost targets, professionalism, responsiveness to customer needs, and long-term relationship with supplier as performance criteria of suppliers for Chinese purchasing managers. De Boer et al. (1998) examined turnover, distance, cost level, and quality image as criteria for evaluating suppliers.

Tam and Tummala (2001) introduced two strategic issues of cost and quality. Then they have broken down the cost issue into capital expenditure and operating expenditure, and similarly the quality issue into technical, operational and vendor criteria. In the next level they have divided these aforementioned criteria into more sub-criteria for vendor selection of telecommunication system. Wang et al. (2004) applied four criteria of delivery reliability with sub-criteria of delivery performance, fill rate, order fulfillment lead time, and perfect order fulfillments; flexibility and responsiveness with sub-criteria of supply chain responsiveness, and production flexibility; cost with sub-criteria of total logistic management cost, value-added employee productivity, and warranty costs; and finally, assets with sub-criteria of cash-to-cash cycle time, inventory days of supply and asset turns. Shyur and Shih (2006) proposed the following criteria: on-time delivery, product quality, price/cost, facility and technology, responsiveness to customer needs, professionalism of salesperson, and relationship with vendor. Chen et al. (2006) used 5 criteria of profitability of supplier, relationship closeness, technological capability, conformance quality and conflict resolution in their work. Guneri et al. (2009), reviewing an accumulated body of criteria appeared in literature since 1966 Dickson (1966), Lehmann and O'Shaughnessy (1974), Abratt (1986), Weberet al. (1991), Min and Galle (1999), Stavropolous (2000), Ghodsypour and O'Brien (2001), Chan & Kumar (2007), Chen et al. (2006), Lin and Chang (2008), summarized 35 essential criteria for supplier selection.

In supply chain management process, the firm select best supplier takes the competitive advantage to other companies. Then, supplier selection process is an important issue and needs to the multiple criteria decision making approach includes both tangible and intangible factors (Guneri et al., 2009). Over the years, several techniques have been developed to solve the problem efficiently. Analytic hierarchy process (AHP), analytic network process (ANP), linear programming (LP), mathematical programming, multi-objective programming, data envelopment analysis (DEA), neural networks (NN), case-based reasoning (CBR) and fuzzy set theory (FST) methods have been applied in literature (Guneri et al., 2009). Also, the integration of different methodologies has been developed in literature and the integration takes the advantages of various methods' strengths and complements their weaknesses.

Ghodsypour and O'Brien (1998) applied an integration of AHP and LP to consider both tangible and intangible factors. Ha and Krishnan (2008) developed a hybrid method including AHP, DEA and NN methodologies. Moreover, Faez et al. (2009) presented an integrated fuzzy case-based reasoning and mathematical programming model.

In practice, decision-making in supplier selection problem includes a high degree of fuzziness and uncertainties. Fuzzy set theory is one of the effective tools to handle uncertainty and vagueness. Kumar et al. (2006) developed a ''fuzzy multi-objective integer programming vendor selection problem'' (f-MIP_VSP) model. In the proposed model, various input parameters have been treated as vague with a linear membership function of fuzzy type. Ghodsypour et al. developed a fuzzy multi-objective linear model and for the first time applied an asymmetric fuzzy decision making technique to enable the decision-makers to assign different weights to various criteria (Amid et al., 2006). Chen et al. (2006) developed a fuzzy and linear programming integrated model to solve multiple sourcing supplier selection problems. Guneri et al. (2009) applied an integrated fuzzy and linear programming approach to the supplier selection problem.

There are a number of papers discussing multi criteria decision making with various applications; for example, operations research, mathematical models and decision theory. Recently, in a survey, Toloie-Eshlaghy and Homayonfar (2011) conducted a review to deal with the current researches on MCDM methodologies and applications from 1999 to 2009 in ScienceDirect's top journals around this subject. Based on their scheme, 628 scholarly papers from 20 journals are categorized into application and non-application areas. The application areas includes 386 papers (61.5%), that categorized into twelve areas on the topics of Environment Management (34 papers), Water Management (22 papers), Business and Financial Management (50 papers), Transportation and Logistics (78 papers), Manufacturing and Assembly (35 papers), Energy Management (20 papers), Agricultural and Forestry Management (12 papers), Managerial and Strategic Planning (43 papers), Project Management and Evaluation (38 papers), Social service (11 papers), Military Service (8 papers) and Other Topics (35 papers). In the context of Transportation and Logistic, 78 papers were published among them, 28 papers are related to supplier selection problem (see Table 1).

Table 1: The applied papers on the topic of 'Transportation and Logistics', related to supplier selection

Author(s)	Application Area	Tools / Methodologies used
Amid et al. (2006)	Supplier selection	Fuzzy MOP
Amid et al. (2009)	Supplier selection in SCM	Fuzzy MOP
Araz et al. (2007)	Outsourcer/supplier selection	PROMETHEE-FGP
Boran et al. (2009)	Supplier selection	Fuzzy TOPSIS
Bottani and Rizzi (2008)	Suppliers and products selection	FAHP-Cluster analysis
Çelebi and Bayraktar (2008)	Supplier evaluation	DEA-NN
Chan and Kumar (2007)	Global supplier development	FAHP
Chen (2009)	Supplier selection (rebuy procurement)	Fuzzy set theory
Chen et al. (2006)	Supplier evaluation in SCM	Fuzzy TOPSIS-Fuzzy MOP
Chou and Chang (2008)	Supplier selection	Fuzzy SMART
Demirtas and Üstün (2008)	Supplier selection and order allocation	ANP-MOMILP
Efendigil et al. (2008)	Selecting a third-party reverse logistics	FAHP–ANN
Guneri et al. (2009)	provider	Fuzzy set theory-Fuzzy LP
Hassanzadeh-Amin and Razmi (2009)	Supplier selection problem in SCM	Fuzzy set theory
Kinra and Kotzab (2008)	Supplier selection and evaluation	AHP
Liao and Rittscher (2007)	Supply chain environmental complexity	Stochastic MOP
Liou and Chuang (2009)	Supplier selection model	DEMATEL-ANP-VIKOR
Liu and Hai (2005)	Selection of outsourcing providers	Voting AHP-DEA
Montazer et al. (2009)	Supplier selection	Fuzzy ELECTRE III
Önüt et al. (2009)	Vendor selection	ANP-TOPSIS
Shyur and Shih (2006)	Supplier selection	ANP-TOPSIS-NGT
	Strategic vendor selection	AHP
Tam and Tummala (2001)	Vendor selection	ANP-Choquet integral
TseAng et al. (2009)	Selection of optimal supplier in SCM	ANP-MOMILP
Ustun and Demırtas* (2008)	Supplier selection	DS-grey related analysis
Wu (2009)	Supplier selection	ANP-MIP (Mixed integer pro-
Wu et al.*** (2009)	Supplier selection	gramming)
Xia and Wu (2007)	Supplier selection	AHP-MOMIP
Yang et al. (2008)	Vendor selection	FAHP-ISM

MATERIALS AND METHODS

Based on the Yücenur et al. (2011), the criteria and attributes identified for supplier selection problem in literature, can be seen in the following four categories (see Table 2):

For conducting this research, we used these 28 criteria as the start point. These criteria were sent in the frame of a questionnaire to a group, consist of 35 experts in manufacturers of the catalytic converter for automobile exhaust in Iran auto industry, in order to determine importance of each criterion based on the 7 point scale (see fig. 1).

Table 2: The hierarchy of the supplier selection problem (Yücenur et al., 2011)

Service quality	Reliability, Just in time delivery, Supply capacity, Innovative properties, Quality of transport place, Flexibility and agility, Non-damaged transport, Communication easiness
Cost	Product price, Lead cost, Shipping and distribution cost, Quality cost, Tariff and custom duties, Delay cost
Risk Factors	Order delays, Political stability, Economy, Customer complaints, Geographical structure, Terrorism, Climate conditions, Cultural differences
Supplier's Characteristics	Management and organizational structure, Financial status, Reputation, Experience, Relationship closeness, Legality

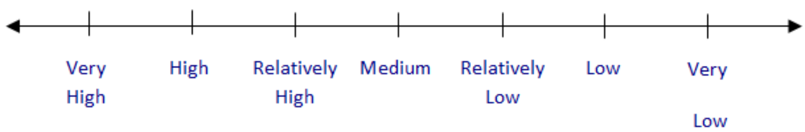

Fig. 1. Seven point scale

33 questionnaires (from 35 questionnaires) were completed by the industry experts. To check the reliability of questionnaires, the Cronbach Alpha was (0.822) which is a very appropriate score for the reliability of responses. Finally the questionnaires were analyzed using Binomial and W Kendal tests in SPSS 16 and 6 criteria were extracted as more essential criteria for supplier selection in auto part manufacturing industry which listed as: Reliability, Average Delay, Quality of Transport Place, Product price, Reputation and Experience.

The second questionnaire has two parts: (a) A pairwise comparison matrix with six criteria that must be compared based on the linguistic values and, (b) a decision matrix with six criteria and four suppliers (alternatives) that must be compared based on the criteria. Gathering data from distribution of this questionnaire, weight of each main criterion obtained through the extension analysis method. These weights used in PROMETHEE method.

THE TWO STEPS FUZZY-AHP AND PROMETHEE METHODOLOGY

In order to designing the supplier selection model, we used two techniques among MCDM methods. Fuzzy multiple attribute decision-making (FMADM) methods have been developed owing to the imprecision in assessing the relative importance of attributes. Imprecision may arise from a variety of reasons: unquantifiable information, incomplete information, unobtainable information and partial ignorance. Conventional MADM methods cannot effectively handle problems with such imprecise information. To resolve this difficulty, fuzzy set theory, first introduced by Zadeh, has been used and is adopted here. We use AHP as MADM technique with fuzzy logic. The weights that are gained from fuzzy-AHP (Extension Analysis) calculations are considered in PROMETHEE calculations. It must be emphasized that the weights of fuzzy-AHP is resulted from a group decision matrix that obtained from combination of individual pairwise comparison matrixes by geometric mean. Similarly, PROMETHEE group decision making matrix, obtained by a same way. Solving the resulted group decision matrix by PROMETHEE method, the preference order of the raw material suppliers could be obtained. The levels of two methodologies are detailed theoretically in following subsections.

Fuzzy AHP Method

There are many fuzzy-AHP methods proposed by various authors (Buckley, 1985; Chang, 1996; Cheng, 1997; Deng, 1999; Leung and Cao, 2000; Mikhailov, 2004; Van Laarhoven and Pedrycz, 1983). These methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Decision-makers usually find that it is more confident to give interval judgments than fixed value judgments. This is because usually they are unable to explicit about their preferences due to the fuzzy nature of the comparison process (Gumus, 2009).

In 1983, two Dutch researchers, Van Laarhoven and Pedrycs (1983) proposed a fuzzy hierarchical analytic process based on the logarithmic least squares. This method has much calculation and was too complicated. In 1996 another method called “Extension Analysis” developed by a Chinese researcher Chang (1996) that was an extension of Van Laarhoven and Pedrycz (1983) method. The used numbers in this method were fuzzy triangular numbers, too. In this study, we use Chang (1996) extension analysis method. The steps of Chang’s extent analysis can be given as in the following:

Step 1: The value of fuzzy synthetic extent with respect to the *i-th* object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad (1)$$

To obtain , perform the fuzzy addition operation of m extent analysis values for a particular matrix, as

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j \right) \quad (2)$$

And to obtain , perform the fuzzy edition operation of m extent analysis values for a particular matrix such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i \right) \quad (3)$$

And then compute the inverse of the vector in above equation, such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (4)$$

Step 2: The degree of possibility of $M_1=(l_1, m_1, u_1) \geq M_2=(l_2, m_2, u_1)$ is defined as $V(M_1 \geq M_2) = \sup[\min(\mu_{M1}(x), \mu_{M2}(y))]$ and can be equivalently expressed as follows:

$$V(M_1 \geq M_2) = hgt\,(M_1 \cap M_2) = \mu_{M_1}(d)$$
$$= \begin{cases} 1 & if \quad m_1 \geq m_2 \\ 0 & if \quad l_2 \geq u_1 \\ \dfrac{u_1 - l_2}{(u_1 - l_2) + (m_2 - m_1)} & otherwise \end{cases} \quad (5)$$

Where d is the ordinate of the highest intersection point D between μ_{M1} and μ_{M2} Fig. 2.

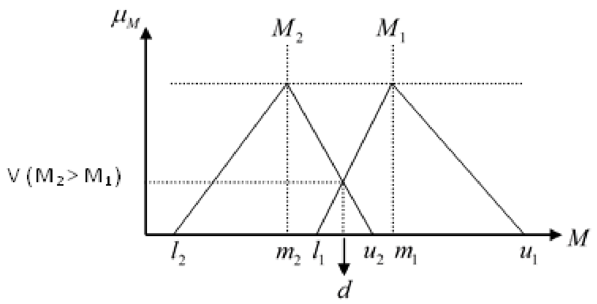

Fig. 2. The intersection between M1 and M2

Step 3: The possibility degree for a convex fuzzy number to be greater than k convex fuzzy numbers M_i $(i = 1, 2, \ldots, k)$ can be defined by,

$$\begin{aligned} &V(M \geq M_1, M_2, \ldots, M_k) = \\ &V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and} \ldots \text{and} (M \geq M_k)], \\ &= \min V(M \geq M_i), \quad (i = 1, 2, \ldots, k) \end{aligned} \quad (6)$$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$ for $i = 1, 2, \ldots, k;\ k \neq i$. Then the weight factor is given by

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \quad (7)$$

Where, Ai $(i = 1, 2, \ldots, n)$ are n elements.

Step 4: Via normalization, the normalized weights vector is,

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \quad (8)$$

Where W is a non-fuzzy number.

PROMETHEE Method

The Multi-Criteria Decision Aid (MCDA) has been one of the very fast growing areas of Operational Research during the two last decades. The MCDA often deals with ranking of many concrete alternatives from the best to the worst ones based on multiple conflicting criteria. The PROMETHEE method (Preference Ranking Organization Method for Enrichment Evaluations) is one of the most recent MCDA methods that was developed by Brans (1982) and further extended by Vincke and Brans (1985). PROMETHEE is an outranking method for a finite set of alternative actions to be ranked and selected among criteria, which are often conflicting. PROMETHEE is also a quite simple ranking method in conception and application compared with the other methods for multi -criteria analysis (Brans et al., 1986). Therefore, the number of practitioners who are applying the PROMETHEE method to practical multiple criteria decision problems and researchers who are interested in sensitivity aspects of this method, increases year by year as can be illustrated by increasing numbers of scholarly papers and conference presentations.

A brief review of PROMETHEE

The PROMETHEE family of outranking methods, including the PROMETHEE I for partial ranking of the alternatives and the PROMETHEE II for complete ranking of the alternatives, were developed by Brans and presented for the first time in 1982 at a conference organized by Nadeau and Landry at the University Laval, Quebec, Canada (Brans, 1982). A few years later, several versions of the PROMETHEE methods such as the PROMETHEE III for ranking based on interval, the PROMETHEE IV for complete or partial ranking of the alternatives when the set of viable solutions is continuous, the PROMETHEE V for problems with segmentation constraints (Brans & Mareschal, 1992), the PROMETHEE VI for the human brain representation (Brans and Mareschal, 1995), the PROMETHEE GDSS for group decision- making (Macharis et al., 1998), and the visual interactive module GAIA (Geometrical Analysis for Interactive Aid) for graphical representation

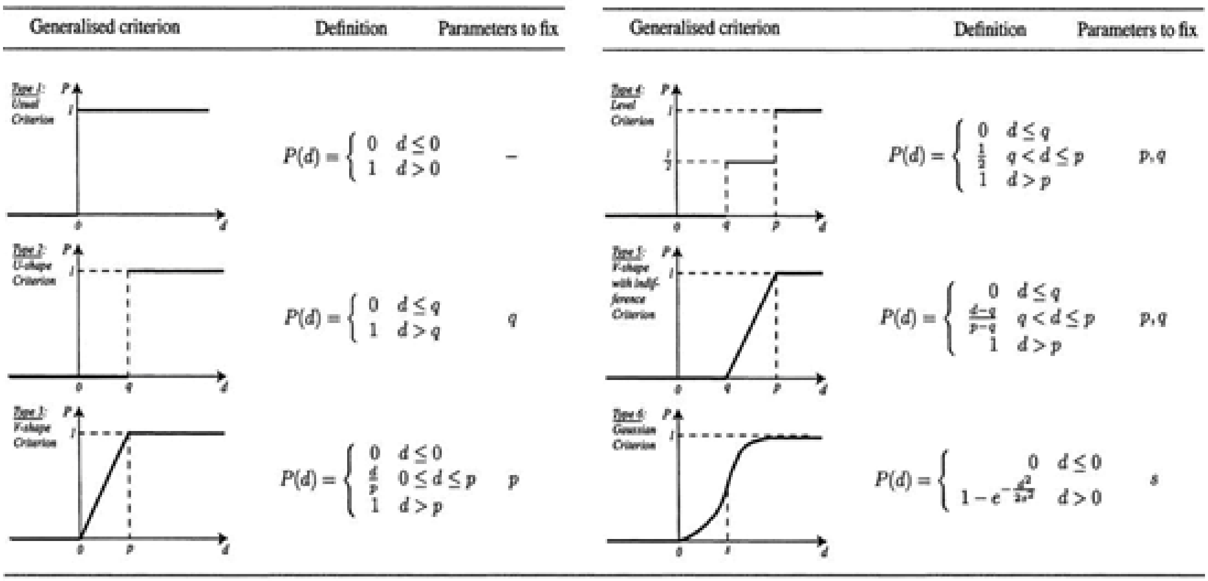

Fig. 3. Types of generalized criteria (Figueira et al., 2005)

(Mareschal & Brans, 1988; Brans and Mareschal, 1994) were developed to help in more complicated decision-making situations (Brans and Mareschal, 2005; Figueira et al. (2004) has recently proposed two extended approaches on PROMETHEE, called as the PROMETHEE TRI for dealing with sorting problems and the PROMETHEE CLUSTER for nominal classification.

The methods of PROMETHEE have successfully been applied in many fields and a number of researchers have used them in decision making problems: Beynon and Wells (2008), Albadvi et al. (2007), Zhang et al. (2006), Wang and Yang (2007), Roux et al. (2008), Doukas et al. (2006), Coelho et al. (2003) and Coelho and Bouillard (2005). A comprehensive literature review, based on a study of scholarly journals, was conducted by behzadian et al. (2009) as a research methodology to build a framework for PROMETHEE research since 1985, time that one of the first papers on the subject of PROMETHEE was published by the Management Science journal.

PROMETHEE II stepwise procedure

This part of the paper briefly describes PROMETHEE II, which is intended to provide a complete ranking of a finite set of feasible alternatives from the best to the worst. This method is fundamental to implement the other PROMETHEE methods and the majority of researchers have referred to this version of the PROMETHEE methods. The PROMETHEE methods have some requisites of an appropriate multi-criteria method and their success is basically due to their mathematical properties and to their particular friendliness of use (Brans and Mareschal, 2005). The basic principle of PROMETHEE II is based on a pairwise comparison of alternatives along each recognized criterion. Alternatives are evaluated according to different criteria, which have to be maximized or minimized. The implementation of the PROMETHEE II requires two additional types of information: First, The weights that Determination of them is an important step in most multi-criteria methods. PROMETHEE II assumes that the decision-maker is able to weigh the criteria appropriately, at least when the number of criteria is not too large (Macharis et al., 2004). Second, The preference function that for each criterion, the preference function translates the difference between the evaluations obtained by two alternatives into a preference degree ranging from zero to one. In order to facilitate the selection of a specific preference function, Vincke and Brans (1985) proposed six basic types as follow: (1) usual criterion, (2) U-shape criterion, (3) V-shape criterion, (4) level criterion, (5) V-shape with indifference criterion and (6) Gaussian criterion.

These six types are particularly easy to define. For each criterion, the value of an indifference threshold, **q**; the value of a strict preference threshold, **p**; and the value of an intermediate value between **p** and **q**, s, has to be fixed (Brans and Mareschal, 1992). In each case, these parameters have a clear significance for the decision-

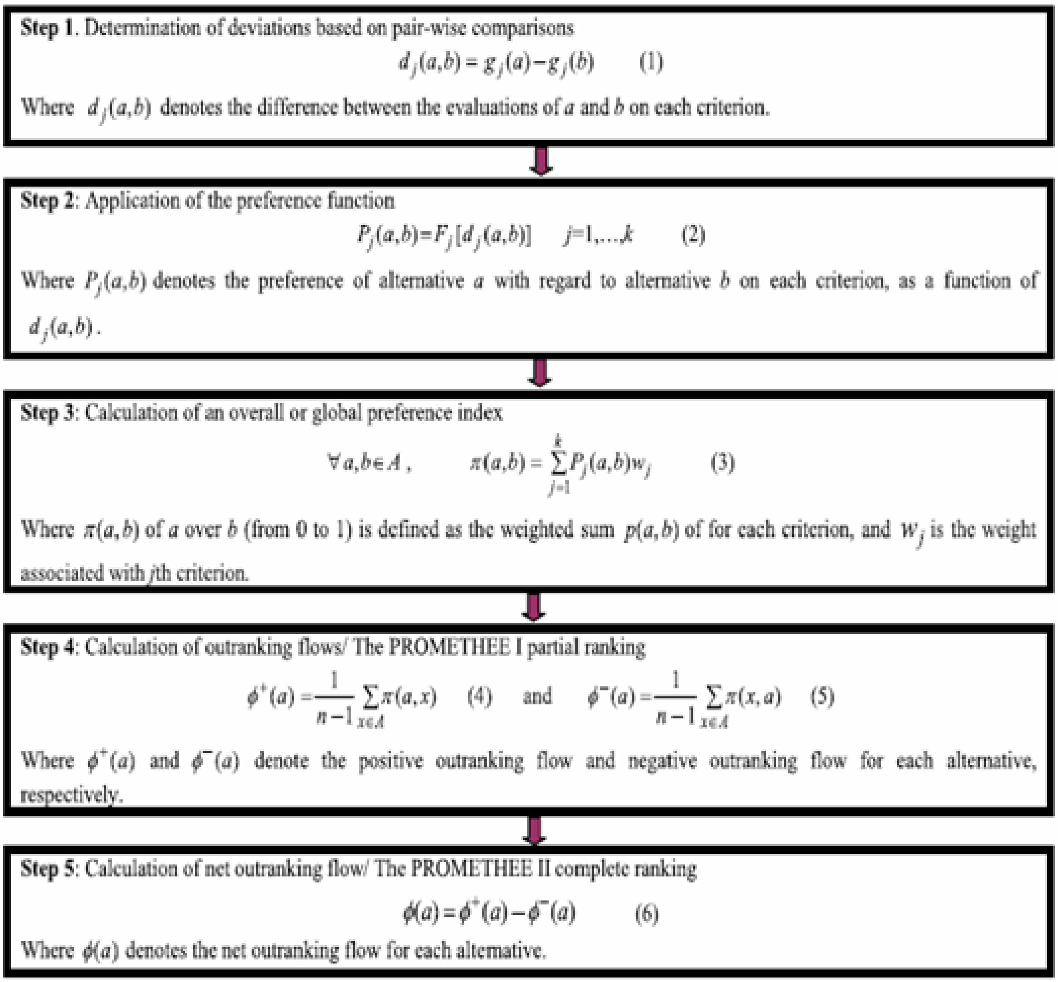

Fig. 3. Types of generalized criteria (Figueira et al., 2005)

maker. Fig.4. presents stepwise procedure for implementing PROMETHEE II.

In the PROMETHEE II, the consideration of net flow leads to complete ranking. The higher the net outranking flow, the better the alternative. A geometrical representation of a decision problem can also be associated with PROMETHEE II. k-dimensional alternatives are projected on a two-dimensional plane (GAIA plane) calculated from a principal component analysis (Le Téno & Mareschal, 1998).

EMPIRICAL EXAMPLE

We Assume readers are familiar with basis of AHP. Phase I: In this section we calculate the weights of main criteria based on the definitions and concepts provided on EA method. So that, after filling the pair-wise comparisons matrix based on the fuzzy comparison measures (see Table 2) by 4 Foumnan-Part Co. experts, we checked the consistency of each matrix by and then combined these by means of weighted geometric mean $W' = (\tilde{a}_i^{W_1} \otimes \ldots \otimes \tilde{a}_2^{W_2} \otimes \tilde{a}_i^{W_i})^{\frac{1}{\Sigma W_i}}$, into a group pair-wise comparisons matrix illustrated in Table 4. Note that the weights of 4 experts considered as $W_1 = 4$, $W_1 = 3$, $W_1 = 2$ and $W_1 = 1$. Below, first the outlines of the extent analysis method on fuzzy AHP are given and then PROMETHEE applied to a supplier selection problem.

The values of fuzzy synthetic extent with respect to the *i-th* object are:

Table 3: Fuzzy triangular variables

Linguistic terms	Equal	Weak advantage	Not bad	Preferable	Good	Fairly good	Very good	Absolute	Perfect
Triangular fuzzy numbers	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(3, 4, 5)	(4, 5, 6)	(5, 6, 7)	(6, 7, 8)	(7, 8, 9)	(8, 9, 10)

Table 4: Pairwise comparison matrix

Criteria	Reliability	Average Delay	Quality of transport place	Product price	Experience	Reputation
Reliability	1, 1, 1	0.306, 0.443, 0.812	0.644, 0.871, 1.246	0.280, 0.392, 0.660	0.699, 1.267, 2.013	0.896, 1.414, 1.933
Average Delay	1.231, 2.259, 3.270	1, 1, 1	1.231, 1.712, 2.107	0.413, 0.644, 1.054	1.597, 2.107, 2.633	2.024, 2.847, 3.641
Quality of transport place	0.803, 1.149, 1.552	0.475, 0.584, 0.812	1, 1, 1	0.261, 0.355, 0.568	0.794, 1.282, 1.835	1.182, 1.783, 2.421
Product price	1.516, 2.551, 3.565	0.949, 1.552, 2.421	1.762, 2.814, 3.837	1, 1, 1	1.455, 2.313, 3.288	1.933, 3.031, 4.076
Experience	0.497, 0.789, 1.431	0.380, 0.475, 0.626	0.545, 0.780, 1.259	0.304, 0.432, 0.687	1, 1, 1	0.826, 1.084, 1.473
Reputation	0.517, 0.707, 1.116	0.275, 0.351, 0.494	0.413, 0.561, 0.846	0.245, 0.330, 0.517	0.679, 0.922, 1.210	1, 1, 1

S_1 = (3.825, 5.387, 7.664) (0.017, 0.023, 0.032) = (0.064, 0.123, 0.246)

S_2 = (0.126, 0.241, 0.440),

S_3 = (0.076, 0.140, 0.263),

S_4 = (0.145, 0.303, 0.584)

S_5 = (0.060, 0.104, 0.208),

S_6 = (0.053, 0.088, 0.167)

Then, we calculate the degree of possibility of M_1 to M_2, M_3, M_4, M_5, M_6. The degree of possibility of each criterion must be calculated relative to other criteria. The possibility degree for a convex fuzzy number to be greater than k convex fuzzy numbers M_i $(i = 1, 2, \dots, k)$ can be defined by :

$V(S_1 \le S_2, S_3, S_4, S_5, S_6)$ = (0.503, 0.907, 0.360, 1.000, 1.000)

$V(S_2 \le S_1, S_3, S_4, S_5, S_6)$ = (1.000, 1.000, 0.828, 1.000, 1.000)

$V(S_3 \le S_1, S_2, S_4, S_5, S_6)$ = (1.000, 0.576, 0.421, 1.000, 1.000)

$V(S_4 \le S_1, S_2, S_3, S_5, S_6)$ = (1.000, 1.000, 1.000, 1.000, 1.000)

$V(S_5 \le S_1, S_2, S_3, S_4, S_6)$ = (0.884, 0.374, 0.784, 0.241, 1.000)

$V(S_6 \le S_1, S_2, S_3, S_4, S_5)$ = (0.747, 0.209, 0.635, 0.091, 0.871)

Assume that for . Then the weight factor is given by

W ' = (0.360 , 0.828 , 0.421 , 1.000 , 0.241 , 0.091)

Via normalization, the normalized weights vector is;

W = (0.122 , 0.281 , 0.143 , 0.340 , 0.082 , 0.031)

According to above weights vector, the criteria; (1) *functions,* (2) *specifications*, (3 *rate*, (4) *satisfactory,* (5) and (6) *budget,* respectively, were known as the most effective success criteria in supplier selection.

To implement PROMETHEE, DECISION LAB software has been applied, which support PROMETHEE I, PROMETHEE II and GAIA plane. It has also Walking Weights and Stability Intervals tools for sensitivity analysis on evaluation results.

Phase II: Evaluation of 4 suppliers based on the main success criteria by Fouman-Part managers leaded to 4 individual decision matrixes. By applying weighted geometric mean $W' = (\tilde{a}_i^{w_1} \otimes \dots \otimes \tilde{a}_2^{w_2} \otimes \tilde{a}_i^{w_i})^{\frac{1}{\Sigma w_i}}$ to combine these

Table 5: Group decision making matrix

	Reliability	Average Delay	Quality of transport place	Product price	Experience	Reputation
Supplier A	7.766	90.000	7.268	2000.000	6.446	7.766
Supplier B	8.320	90.000	7.268	1900.000	8.277	8.653
Supplier C	5.323	60.000	3.684	2100.000	2.757	4.866
Supplier D	6.900	75.000	6.997	2200.000	7.435	7.908

Table 6: criteria list in Supplier evaluation

Criterion name	Type	Weight	Unit	Preference function
Reliability	Max	0.122	Scale (changed to Number)	Usual
Average delay	Min	0.281	Number	Usual
Quality of transport place	Max	0.143	Scale (changed to Number)	Usual
Product price	Min	0.340	Number	Usual
Experience	Max	0.082	Scale (changed to Number)	Usual
Reputation	Max	0.031	Scale (changed to Number)	Usual

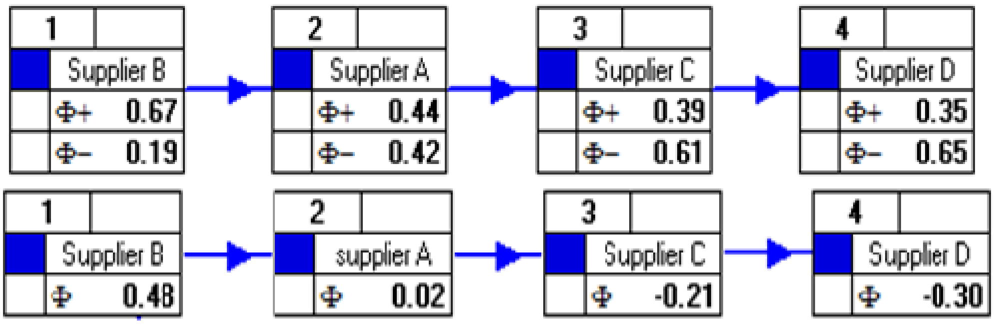

Fig. 5. The results of the evaluation of the suppliers through PROMETHEE II

matrixes, the group decision matrix resulted as Table 4. Note that, the weights of the 4 Fouman-Part Co. experts are 4, 3, 2 and 1.

There were some qualitative criteria in selection process. Since we used weighted geometric mean to combine individual decision matrixes, these criteria in group decision matrix lost their nature and their scale turned into numeric unit. In this evaluation, the type of each criterion has been considered as Table 6.

In this section, the results of implementation of the model along with sample of the four suppliers of Fouman-Part Company are presented. Evaluation through DECISION LAB software on with the help of the experts of Fouman-Part Company, carried out for material suppliers and the results are shown in Figures 5.

Based on the outranking flow in PROMETHEE II, Supplier B, A, C and D, respectively were identified as suppliers of row materials for Fouman-Part Company.

CONCLUSION

In this paper, a combined decision-making model is provided for evaluating suppliers a in supplier selection problem. Evaluation and ranking of the most important criteria in supplier selection of a part producer company in Iran car manufacturing industry has been done by Extension Analysis (A Fuzzy AHP technique). Then, ranking of the suppliers have been performed by PROMETHEE decision-making method by means of DECISION LAB software. The required information for implementing of this method has been gathered and analyzed through structured two steps questionnaire that was filled in by the industry experts.

ACKNOWLEDGEMENT

Authors want to appreciate Dr. Khosousi, the chief executive of Fouman-Part Company and all experts helped us to perform this study.

REFERENCE

Abratt, R. (1986). Industrial buying in high-tech markets. *Industrial marketing management, 15*(4), 293-298.

Aissaoui, N., Haouari, M., & Hassini, E. (2007). Supplier selection and order lot sizing modeling: *A review. Computers & operations research, 34*(12), 3516-3540.

Amid, A., Ghodsypour, S. H., & O'Brien, C. (2006). Fuzzy multiobjective linear model for supplier selection in a supply chain. *International Journal of production economics, 104*(2), 394-407.

Amin, S. H., & Razmi, J. (2009). An integrated fuzzy model for supplier management: A case study of ISP selection and evaluation. *Expert systems with applications, 36*(4), 8639-8648.

Amid, A., Ghodsypour, S. H., & O'Brien, C. (2009). A weighted additive fuzzy multiobjective model for the supplier selection problem under price breaks in a supply chain. *International Journal of Production Economics, 121*(2), 323-332.

Albadvi, A., Chaharsooghi, S.K., & Esfahanipour, A. (2007). Decision making in stock trading: An application of PROMETHEE. *European Journal of Operational Research, 177*(2), 673–683.

Araz, C., Ozfirat, P. M., & Ozkarahan, I. (2007). An integrated multicriteria decision-making methodology for outsourcing management. *Computers & Operations Research, 34*(12), 3738-3756.

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2009). PROMETHEE: A comprehensive literature review on methodologies and applications. *European journal of Operational research, 200*(1), 198-215.

Beynon, M. J., & Wells, P. (2008). The lean improvement of the chemical emissions of motor vehicles based on preference ranking: A PROMETHEE uncertainty analysis. *Omega, 36*(3), 384-394.

Boran, F.E., Genç, S., Kurt, M., & Akay, D. (2009). A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. *Expert Systems with Applications, 36*(8), 11363-11368.

Bottani, E., & Rizzi, A. (2008). An adapted multi-criteria approach to suppliers and products selection-An application oriented to lead-time reduction. *International Journal of Production Economics, 111*(2), 763-781.

Brans, J. P. (1982). L'ingenierie de la decision, l'laboration d'instruments d'aidea la decision. Colloque sur l'Aidea la Decision. *Faculte des Sciences de l'Administration, Universite Laval*.

Brans, J.P., & Mareschal, B. (1992). PROMETHEE V: MCDM problems with segmentation constraints. INFOR: *Information Systems and Operational Research, 30*(2), 85-96.

Brans, J. P., & Mareschal, B. (1995). The PROMETHEE VI procedure: how to differentiate hard from soft multicriteria problems. *Journal of Decision Systems, 4*(3), 213-223.

Brans, J.P., & Mareschal, B. (2005). PROMETHEE methods. In Multiple criteria decision analysis: state of the art surveys (pp. 163-186). *Springer New York*.

Brans, J. P., Vincke, P., & Mareschal, B. (1986). How to select and how to rank projects: The PROMETHEE method. *European journal of operational research, 24*(2), 228-238.

Brans, J. P., Macharis, C., Kunsch, P. L., Chevalier, A., & Schwaninger, M. (1998). Combining multicriteria decision aid and system dynamics for the control of socio-economic processes. An iterative real-time procedure. *European Journal of Operational Research, 109*(2), 428-441.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy sets and systems, 17*(3), 233-247.

Brans, J. P., & Vincke, P. (1985). Note-A Preference Ranking Organisation Method: (The PROMETHEE Method for Multiple Criteria Decision-Making). *Management science, 31*(6), 647-656.

Çelebi, D., & Bayraktar, D. (2008). An integrated neural network and data envelopment analysis for supplier evaluation under incomplete information. *Expert Systems with Applications, 35*(4), 1698-1710.

Chan, F. T., & Kumar, N. (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. *Omega, 35*(4), 417-431.

Chen, C. T., Lin, C. T., & Huang, S. F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *International journal of production economics, 102*(2), 289-301.

Chen, C. M. (2009). A fuzzy-based decision-support model for rebuy procurement. *International Journal of Production Economics, 122*(2), 714-724.

Chen, C. T., Lin, C. T., & Huang, S. F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *International journal of production economics, 102*(2), 289-301.

Chou, S. Y., & Chang, Y. H. (2008). A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach. *Expert systems with applications, 34*(4), 2241-2253.

Coelho, R. F., & Bouillard, P. (2005). A multicriteria evolutionary algorithm for mechanical design optimization with expert rules. *International journal for numerical methods in engineering,*

62(4), 516-536.
Coelho, R. F., Bersini, H., & Bouillard, P. (2003). Parametrical mechanical design with constraints and preferences: application to a purge valve. *Computer methods in applied mechanics and engineering, 192*(39), 4355-4378.
De Boer, L., van der Wegen, L., & Telgen, J. (1998). Outranking methods in support of supplier selection. *European Journal of Purchasing & Supply Management, 4*(2-3), 109-118.
Demirtas, E. A., & Ustun, O. (2009). Analytic network process and multi-period goal programming integration in purchasing decisions. *Computers & Industrial Engineering, 56*(2), 677-690.
Dickson, G.W.(1966). An analysis of vendor selection systems and decisions. *Journal of Purchasing, 2*(1), 5-17.
Doukas, H., Patlitzianas, K. D., & Psarras, J. (2006). Supporting sustainable electricity technologies in Greece using MCDM. *Resources Policy, 31*(2), 129-136.
Efendigil, T., Önüt, S., & Kongar, E. (2008). A holistic approach for selecting a third-party reverse logistics provider in the presence of vagueness. *Computers & Industrial Engineering, 54*(2), 269-287.
Faez, F., Ghodsypour, S. H., & O'Brien, C. (2009). Vendor selection and order allocation using an integrated fuzzy case-based reasoning and mathematical programming model. *International Journal of Production Economics, 121*(2), 395-408.
Figueira, J., De Smet, Y., & Brans, J. P. (2004). *MCDA methods for solving sorting and clustering problems: PROMETHEE TRI and PROMETHEE CLUSTER*. Technical Report TR/SMG/2004 -02. Universite Libre de Bruxelles.< http:// code. ulb. ac. be/smg. publications. php>(up dated 2006-11-05).
Figueira, J., Mousseau, V., & Roy, B. (2005). ELECTRE methods. In Multiple criteria decision analysis: State of the art surveys ,133-153, *Springer New York.*
Ghodsypour, S. H., & O'Brien, C. (1998). A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming. *International journal of production economics, 56*, 199-212.
Ghodsypour, S. H., & O'brien, C. (2001). The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint. *International journal of production economics, 73*(1), 15-27.
Gumus, A.T. (2009). Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology. *Expert Systems with Applications, 36*(2) ,4067-4074.
Guneri, A. F., Yucel, A., & Ayyildiz, G. (2009). An integrated fuzzy-lp approach for a supplier selection problem in supply chain management. *Expert Systems with Applications, 36*(5), 9223-9228.
Ha, S. H., & Krishnan, R. (2008). A hybrid approach to supplier selection for the maintenance of a competitive supply chain. *Expert systems with applications, 34*(2), 1303-1311.
Jang, J. S. R., Sun, C. T., & Mizutani, E. (1997). Neuro-fuzzy and soft computing, a computational approach to learning and machine intelligence.
Kinra, A., & Kotzab, H. (2008). A macro-institutional perspective on supply chain environmental complexity. *International Journal of Production Economics, 115*(2), 283-295.
Kumar, M., Vrat, P., & Shankar, R. (2006). A fuzzy programming approach for vendor selection problem in a supply chain. *International Journal of Production Economics, 101*(2), 273-285.
Lehmann, D. R., & O'shaughnessy, J. (1974). Difference in attribute importance for different industrial products. *The Journal of Marketing*, 36-42.
Le Téno, J. F., & Mareschal, B. (1998). An interval version of PROMETHEE for the comparison of building products' design with ill-defined data on environmental quality. *European Journal of Operational Research, 109*(2), 522-529.
Lin, H. T., & Chang, W. L. (2008). Order selection and pricing methods using flexible quantity and fuzzy approach for buyer evaluation. *European Journal of Operational Research, 187*(2), 415-428.
Liao, Z., & Rittscher, J. (2007). A multi-objective supplier selection model under stochastic demand conditions. *International Journal of Production Economics, 105*(1), 150-159.
Liou, J. J., & Chuang, Y. T. (2009). Developing a hybrid multi-criteria model for selection of outsourcing providers. *Expert Systems with Applications, 37*(5), 3755-3761.

Liu, F. H. F., & Hai, H. L. (2005). The voting analytic hierarchy process method for selecting supplier. *International journal of production economics, 97*(3), 308-317.

MACHARIS, C., Brans, J. P., & Mareschal, B. (1998). The GDSS PROMETHEE procedure-A PROMETHEE-GAIA based procedure for group decision support. 283-307.

Mareschal, B., & Brans, J.P. (1988). Geometrical representations for MCDA. The GAIA module. *European Journal of Operational Research, 34*(1), 69–77.

Macharis, C., Springael, J., De Brucker, K., & Verbeke, A. (2004). PROMETHEE and AHP: The design of operational synergies in multicriteria analysis.: Strengthening PROMETHEE with ideas of AHP. *European Journal of Operational Research, 153*(2), 307-317.

Min, H., & Galle, W. P. (1999). Electronic commerce usage in business-to-business purchasing. *International Journal of Operations & Production Management, 19*(9), 909-921.

Mareschal, B., & Brans, J.P. (1994). The PROMETHEE-GAIA decision support system for multicriteria investigations (No. 2013/9367). ULB--Universite Libre de Bruxelles.

Montazer, G. A., Saremi, H. Q., & Ramezani, M. (2009). Design a new mixed expert decision aiding system using fuzzy ELECTRE III method for vendor selection. *Expert Systems with Applications, 36*(8), 10837-10847.

Mummalaneni, V., Dubas, K. M., & Chao, C. N. (1996). Chinese purchasing managers' preferences and trade-offs in supplier selection and performance evaluation. *Industrial Marketing Management, 25*(2), 115-124.

Önüt, S., Kara, S. S., & Işik, E. (2009). Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert systems with applications, 36*(2), 3887-3895.

Roux, O., Duvivier, D., Dhaevers, V., Meskens, N., & Artiba, A. (2008). Multicriteria approach to rank scheduling strategies. *International Journal of Production Economics, 112*(1), 192-201.

Shyur, H. J., & Shih, H. S. (2006). A hybrid MCDM model for strategic vendor selection. *Mathematical and Computer Modelling, 44*(7), 749-761.

Stavropolous, N. (2000). Suppliers In The New Economy Issues confronting suppliers in the B2B e-procurement segment. *Telecommunication Journal of Australia, 50*(4), 27-30.

Swift, C. O. (1995). Preferences for single sourcing and supplier selection criteria. *Journal of Business Research, 32*(2), 105-111.

Tam, M.C., & Tummala, V.R. (2001). An application of the AHP in vendor selection of a telecommunications system. *Omega, 29*(2), 171-182.

Toloie-Eshlaghy, A., & Homayonfar, M. (2011). MCDM methodologies and applications: a literature review from 1999 to 2009. *Research Journal of International Studies, 21*, 86-137.

Tseng, M. L., Chiang, J. H., & Lan, L. W. (2009). Selection of optimal supplier in supply chain management strategy with analytic network process and choquet integral. *Computers & Industrial Engineering, 57*(1), 330-340.

Ustun, O., & Demı, E. A. (2008). An integrated multi-objective decision-making process for multi-period lot-sizing with supplier selection. *Omega, 36*(4), 509-521.

Ustun, O., & Demı, E. A. (2008). An integrated multi-objective decision-making process for multi-period lot-sizing with supplier selection. *Omega, 36*(4), 509-521.

Vaez-Ghasemi, M. (2015). Supplier selection among alternative scenarios by Data envelopment analysis. *Iranian Journal of Optimization, 7*(2), 814-826.

Wang, J. J., & Yang, D. L. (2007). Using a hybrid multi-criteria decision aid method for information systems outsourcing. *Computers & Operations Research, 34*(12), 3691-3700.

Wang, G., Huang, S.H., & Dismukes, J.P. (2004). Product-driven supply chain selection using integrated multi-criteria decision-making methodology. *International journal of production economics, 91*(1), 1-15.

Weber, C.A., Current, J.R., & Benton, W.C. (1991). Vendor selection criteria and methods. *European journal of operational research, 50*(1), 2-18.

Wiecek, M.M., Ehrgott, M., Fadel, G., & Figueira, J.R. (2008). Editorial: Multiple criteria decision making for engineering. *Omega, 36*, 337–339.

Wu, D. D. (2009). Supplier selection in a fuzzy group setting: A method using grey related analysis and Dempster–Shafer theory. *Expert Systems with Applications, 36*(5), 8892-8899.

Wu, W. Y., Sukoco, B. M., Li, C. Y., & Chen, S. H. (2009). An integrated multi-objective decision-making process for supplier selection with bundling problem. *Expert Systems with Applications, 36*(2), 2327-2337.

Xia, W., & Wu, Z. (2007). Supplier selection with multiple criteria in volume discount environments. *Omega, 35*(5), 494-504.

Yang, J. L., Chiu, H. N., Tzeng, G. H., & Yeh, R. H. (2008). Vendor selection by integrated fuzzy MCDM techniques with independent and interdependent relationships. *Information Sciences, 178*(21), 4166-4183.

Yücenur, G. N., Vayvay, Ö., & Demirel, N. Ç. (2011). Supplier selection problem in global supply chains by AHP and ANP approaches under fuzzy environment. *The International Journal of Advanced Manufacturing Technology, 56*(5-8), 823-833.

Zhang, G., Ni, Y., Churchill, J., & Kokot, S. (2006). Authentication of vegetable oils on the basis of their physico-chemical properties with the aid of chemometrics. *Talanta, 70*(2), 293-300.